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ABSTRACT

The need to understand variations of wood characteristics in alternative species that have fast growth and good quality for the consumer market has been increasing given the prominent technological development of wood. This study aimed to evaluate the wood basic density and the anatomical characteristics of *Schizolobium parahyba* and *Eucalyptus urophylla* 3-year old juvenile wood planted in *savanna* soil in a 3x3m spacing. Wood disks and samples were cut in different longitudinal (base-top) and radial (pith-bark) positions from five trees per species to determine the wood's basic density and fiber and vessel dimensions. The *Schizolobium parahyba* wood presented (i) lower basic density, vessel size and vessel frequency, and (ii) higher wood fiber width and diameter than *Eucalyptus urophylla*. The average wood basic density was 0.27 g/cm³ for *S. prahyba* and 0.40 g/cm³ for *E. urophylla* wood.

Keywords: Anatomical characteristics, wood density, fast growing species, Guapuruvu, Eucalyptus.

RESUMO

Face ao desenvolvimento tecnológico da madeira, cresce a necessidade do conhecimento sobre a variação das características da madeira de espécies alternativas, de rápido crescimento e de boa qualidade para o mercado consumidor. O presente trabalho teve como objetivo avaliar a densidade básica e as características anatômicas da madeira de *Schizolobium parahyba* em comparação com o *Eucalyptus urophylla,* aos 3 anos de idade, plantados em solo de cerrado com espaçamento de 3x3m. Para as análises foram selecionadas 5 árvores/espécie e cortados discos de madeira em diferentes posições longitudinais e radiais (medula-casca) para a determinação da densidade básica e amostras das fibras (comprimento, espessura da parede (base-topo), largura total e diâmetro do lumen) e dos vasos (frequência, diâmetro tangencial e percentagem de área ocupada). A análise comparativa das características indicou: (i) menor densidade básica e dimensão e frequência dos vasos e (ii) maior largura e diâmetro do lumem das fibras na madeira do *S. arahyba* em relação a de *E.urophylla*. A densidade básica média foi de 0,27 g/cm³ para o *S. parahyba* e de 0,40 g/cm³ para o *E. urophylla* aos 3 anos de idade.

Palavras-chave: Características anatómicas; densidade da madeira; espécies de rápido crescimento; Guapuruvu, Eucalyptus.

INTRODUCTION

Brazil occupies the second position in the world ranking of forest area with a total of 520 million hectares (12.9% of the forests worldwide) (FAO, 2011) and planted forests total an area of 7.8 million hectares, of which 5.6 million hectares are species of the genus Eucalyptus (IBÁ, 2017). *Eucalyptus* species are the most productive in the Brazilian forest sector with an average yield of 41.3 $m^3.ha^{-1}.year^{-1}$, a result of targeted investments mainly in genetic improvement, soil preparation and tree fertilization (ABRAF, 2013). Despite the prevalence of eucalyptus species, the forestry sector has directed investments to research studies carried out with native species. The use of native species has been gaining ground, as the market is increasingly seeking alternative species with rapid growth, high productivity and good adaptation to soil conditions.

Paricá (*Schizolobium amazonicum*) is highlighted among fast-growing native speciesand has been planted commercially, mainly in the North and Center-West of Brazil, reaching 87,500 ha of commercial crops (ABRAF, 2013). Guapuruvu (*Schizolobium parahyba*) is also considered one of the fastest growing native species. The wood is indicated for manufacturing furniture (after chemical treatment) and compensated panels, and presents volumetric growth rate of up to 45 $m^3.ha^{-1}.year^{-1}$ at 10 years-old (Nisgoski *et al*., 2012).

The growing demand for timber in domestic and foreign markets tends to favor replacing native wood by juvenile reforestation wood, which has become more evident in recent years. Researchers' and the industrial sector's interest in juvenile wood rotations is growing and the use of this wood causes problems associated with fiber quality and low physical-mechanical properties (Vidaurre *et al*., 2011).

Evaluating the anatomical and physical characteristics of the wood is fundamental to define its correct application in the many industrial uses. Basic density is the main measure for wood quality assessment, which along with anatomical characteristics are intrinsic properties that vary among species, individuals and positions in the trunk (pith-bark; base-top) (Trugilho*et al*., 2009).

This study aimed to determine the basic density and the anatomical characteristics of *S. parahyba* and *E. urophylla* juvenile wood both planted in Cerrado soil.

MATERIAL AND METHODS

Study site

The trees were cut down from a forest stand at the State University of Goiás, Ipameri Campus, GO (17° 42' 38" S, 48° 08' 12" W, 825 m height). The climate of the region is classified as tropical with dry winter and wet summer (Aw) according to Köeppen, with an average annual precipitation of 1,447 mm and a mean temperature of 21.9°C. The soil is classified as Oxisol with a clayey texture. The anatomical characteristics and wood density were evaluated in the Bioenergy and Wood Quality Laboratory (LQMBio) of the Federal University of Goiás, Goiânia, GO, Brasil.

Field experiment

The forest stands were implemented in June 2013 and made up of *S. parahyba* (Vell) S.F. Blake trees planted in 0.5 hectares spaced 3.0 m x 3.0 m, and *E. urophylla* S.T. Blake plots planted in 0.2 hectares spaced 3.0 m x 3.0 m. Trees of both species received chemical fertilization with 180 g of NPK formulation 5-30-15 + 0.2 Zn + 0.5 B per pit. The same fertilization was replicated in the coverage in the amount of 110g per plant at 6, 12 and 18 months after planting.

Collection, cutting and sample preparation

Five Guapuruvu and five Eucalyptus trees, 3 years-old, were randomly selected and harvested. Two cross-sectional discs, 5 cm thick, were cut down from each tree along the stem at different height levels (0, 25, 50, 75 and 100% of the commercial height) as shown in Figure 1, to determine fiber (length, wall thickness, lumen diameter and width) and vessels (tangential diameter, frequency and occupied area) dimensions and basic density.

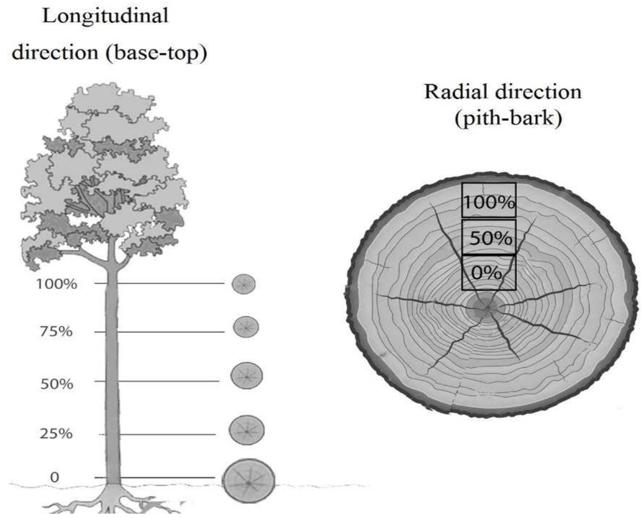

Figure 1 - Sampling of the wood discs from the trees to determine the basic density and anatomical characteristics.

Wood basic density

For wood basic density, one disck per position collected was immersed in water until completely saturated. Then the wet, immersed and dry weight (up to constant weight; 103°±2°C) were obtained following the method proposed by Vital (1984). The wood basic density values per longitudinal position were used to determine the arithmetic mean by tree and after by species and thebase-top variation.

Wood Anatomical characteristics

Radial samples of the wood discs were collected from three positions (0%; near to pith, 50%; intermediate region and 100%; near to bark) and were macerated according to the Franklin method (Johansen, 1940). Histological slides were prepared from the fiber suspension by collecting 15 images/slide under a light microscope to measure its length (100x), and 15 images/slide for width, lumen diameter and wall thickness (400x). Specimens (20 x 10 mm width x thickness) were taken from the same wood samples used in the maceration process (three radial positions; 0, 50 and 100%), and were soaked in boiling water for saturation and softening. These specimens were fixed on microtome slides and cross-sections were cut (15-20 μm thick). Histological sections of the wood were bleached (Javel water), washed (distilled water, acetic acid 1%), dehydrated (alcoholic series, 30-100%), washed (xylol) during 30 min. and then the histological slides were mounted in Canada balsam.

Digital images of transverse section (3 per radial position) were collected from slides prepared under fluorescence microscopy (40x) to measure vessel diameter, % area occupied per vessel and vessel frequency according to the IAWA (1989). *Image Pro Plus* software was used to measure the anatomical variables.

Statistical analyzes

A completely randomized design was used for statistical data analysis. From the data obtained, the outliers were checked by the Box-Plot method, the distribution normality by the Shapiro-Wilk method and the variance heterogeneity by the Bartlett and Levene methods. The data presented normality of distribution and homogeneity of variance, and analysis of variance (ANOVA) was applied, verifying the effect of the species and the radial and longitudinal position on the wood basic density and anatomical characteristics. A regression analysis was carried out to assess the relationship between variables and longitudinal positions.

RESULTS AND DISCUSSION

The wood basic density averages of 3-year-old *E. urophylla* and *S. parahyba* were significantly different, as shown in Table 1.

Table 1 - Mean, maximum and minimum wood basic density per species

Species	Wood basic density ($g.cm^{-3}$)		
	Mean	Maximum	Minimum
E. urophylla	0.40 * (0.03)	0.47 * (0.02)	0.34 * (0.03)
S. parahyba	0.27 (0.06)	0.36 (0.05)	0.10 (0.05)

Means followed by standard deviation. Student t-test: * p<0.05

The Eucalyptus wood basic density observed in this study is in agreement with the values referenced by Gouvêa *et al.* (2011) of 3-year-old *Eucalyptus* sp. clones with maximum and minimum densities ranging from 0.41 to 0.47g.cm^{-3} and by Sette Jr *et al.* (2012) for *E. grandis* at 2, 4 and 6-years old (0.43, 0.44 and 0.46 g.cm^{-3}, respectively).

Studying 16-year-old *E. urophylla*, Oliveira *et al.* (2005) obtained values of 0.54 g.cm^{-3}; 25% higher than those found in this study. The differences in mean wood basic density values are associated with juvenile and adult wood and to the age of the trees. The effect of increasing tree age on wood quality (including basic density) has been reported in the literature by many authors and for several forest species (Zobel and van Buijtenen, 1989; Trugilho *et al*., 1996; Silva *et al*., 2007; Sette Jr .*et al*., 2012), and states that the increase in wood density occurs due to changes in the cambial meristem and to the mechanical-physiological requirements consequent of the tree development process. Such processes are represented by increased wall thickness of the fibers and increased frequency and reduced number of vessels, as the mature wood is formed in the tree trunks.

Scientific studies that have evaluated the characteristics of *S. parahyba* wood are scarce: Andrade and Carvalho (1998) evaluated trees from native vegetation and found wood basic density values of 0.24 g.cm^{-3}, while Athanázio-Heliodoro (2015) evaluated the characteristics of *S. parahyba* wood and obtained mean basic density values of 0.29 g.cm^{-3} in 15-year-old trees.

The analysis of variance indicated a significant sampling position in base-top direction effect in the tree trunks for wood characteristics. Regarding wood basic density, a quadratic variation models was observed for both species, with variation patterns different (i) Eucalyptus: decreased from the base up to approximately 50% of the commercial height, remaining constant or increasing towards the top of the trunk and (ii) Guapuruvu: characterized by a decrease in average wood basic density values from the base (0.28-0.39 g.cm^{-3}) to the top (0.10-0.20 g.cm^{-3}) (Figure 2).

This longitudinal variation of the wood basic density in the tree trunks is similar to those recorded by Panshinand De Zeeuw (1980) and Zobel and Van Buijtenen (1989), who highlight some patterns where the values and behavior of the wood basic density in the longitudinal position will vary depending on age and species.

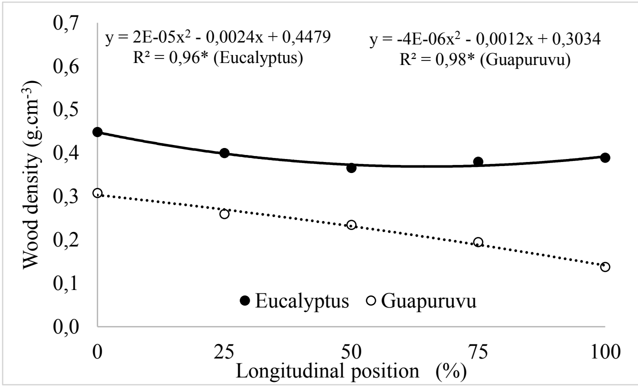

Figure 2 - Variation of basic wood density by specie and longitudinal position.

The higher wood basic density values in the basal region in both species are related to the highest value of fibre wall thickness (Guapuruvu) and the lowest values of tangencial diameter and area ocuppiedby vessels (Eucalyptus). The longitudinal increase of wood density observed in forest species is related to the increase of fibre wall thickness from the base to the top and a possible variation of vessel dimensions and percentage (Quilhó and Pereira, 2001).

There was no significant effect of species in fiber length and wall thickness, with an average length of 873.5 and 869.2 μm and wall thickness of 3.9 and 3.7 μm for Eucalyptus and Guapuruvu, respectively. The Guapuruvu presented higher fiber width and lumen diameter i.e 29.4 μm and 22.0 μm respectively *versus* 19.8 μm and 11.8 μm in Eucalyptus (Table 2).

Table 2 - Fiber dimensions by species

Species	Length (μm)	Width (μm)	Lumen diameter (μm)	Wall thickness (μm)
E. urophylla	873.5 (144.9)	19.8 * (5.1)	11.8 * (3.2)	3.9 (1.1)
S. parahyba	869.2 (178.2)	29.4 (4.1)	22.0 (4.2)	3.7 (1.1)

Means followed by standard deviation. Student t-test: * $p<0.05$

The values recorded for fiber dimensions in this paper are within the range established by the literaturefor trees from 2 to 20 years: 750 to 1400 µm, 12 to 20 µm, 2.5 to 6.0 µm and 6 to 12 µm for length, width, wall thickness and lumen diameter (Bamber *et al*., 1982; Silva *et al*., 2007; Sette Jr *et al*., 2009).

A shortage of scientific studies evaluating the anatomical characteristics of Guapuruvu wood, especially juvenile wood in young trees, make it difficult to discuss the results. In 15-year-old Guapuruvutrees, the length, width, wall thickness and lumen diameter of fibers were 1035.0, 37.9, 3.8 and 30.6 µm, respectively (Nisgoski *et al*., 2012). The mean values of fiber dimensions were smaller than previous records in this study and as mentioned earlier this difference is related to already-formed mature wood.

The fiber dimension variation in the three radial positions of 3-year-old Eucalyptus and Guapuruvu trees is shown in Figure 3.

For both tree species, the length and wall thickness of the fibers increased significantly (p <0.05) from the region near the pith to bark and the width and lumen diameter of fibers decreased, althought only significantely for Guapuruvu.

There is vast literature concerning the radialvariation of wood fiber dimensions in various species and diferente growth conditions. For eucalyptus species several patterns of radial variation have been reported, showing an increase of length and wall thickness and a reduce fiber width and lumen diameter from the pith to the bark (Tomazello Filho, 1985; Jorge *et al*., 2000; Quilhó *et al*., 2006; Silva *et al*., 2007; Sette Jr. *et al*., 2009).

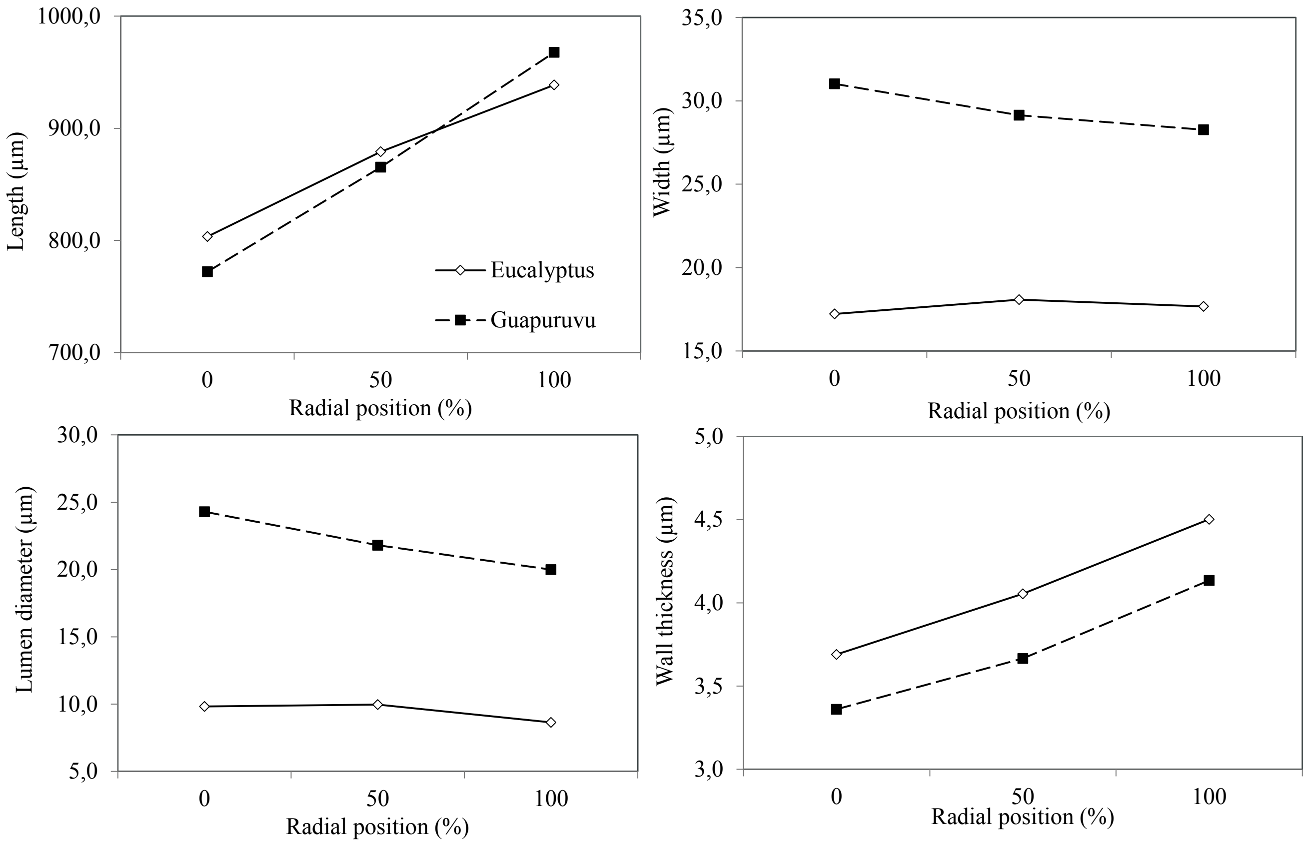

Figure 3 - Variation of fiber dimensions by species and radial position.

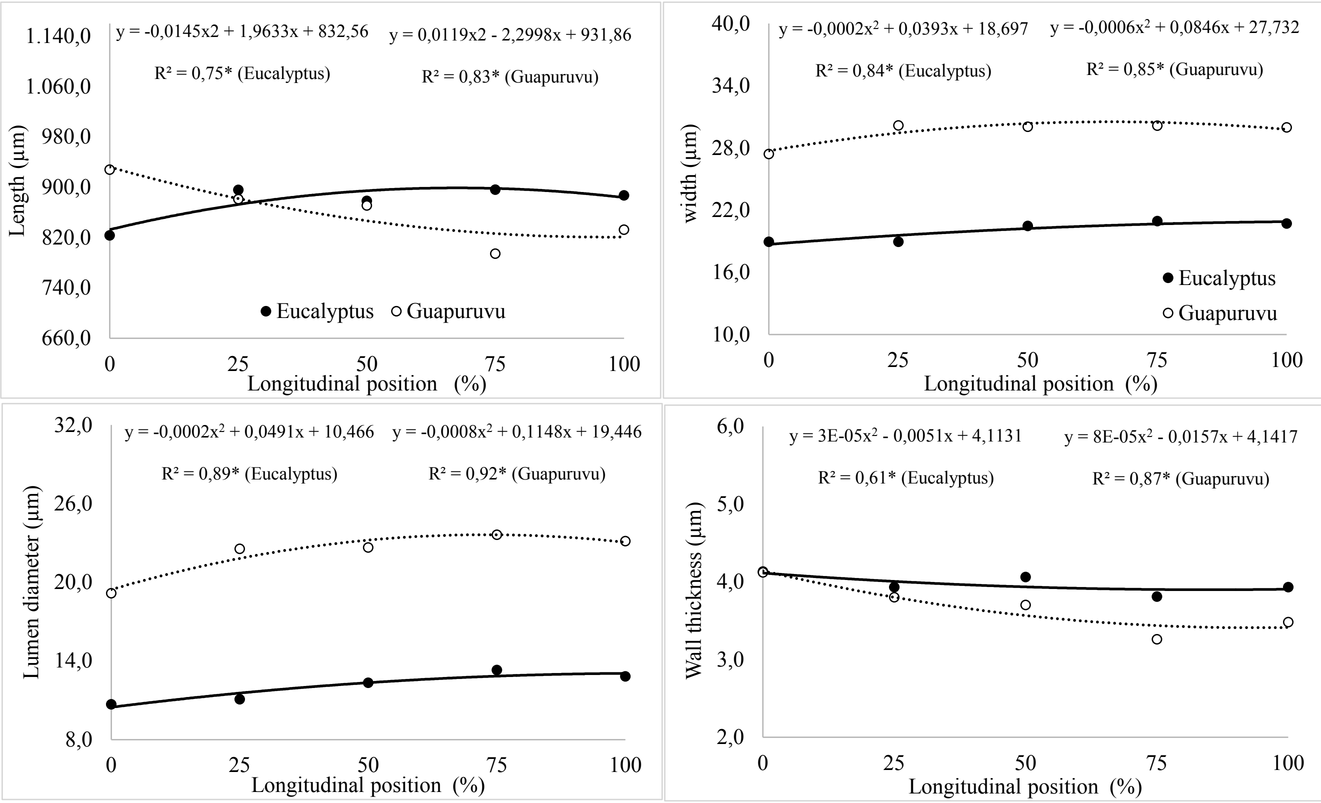

Figure 4 - Variation of fiber dimensions by species and longitudinal position.

Nisgoski *et al.* (2012) verified an increase in length, wall thickness, width and lumen diameter of fibers in the pith-bark direction in 15-year old *S. parahyba*, and Lobão *et al.* (2012) in 21-year old *S. parahyba* var. *amazonicum*.

The analysis of variance indicated a significant effect of base-top direction in the tree trunks for anatomical characteristics. Regarding fiber dimensions, a quadratic variation models was observed for both species with similar variation patterns, except for length and coefficient of determination, ranging from 0.61 to 0.92 (Figure 4).

The fibers of two species had thicker walls at the base (4.12 – 4.13 µm) than the other longitudinal positions (25, 50, 75 e 100%; 3.26 to 4.06 µm). In general, an increase in the width and diameter of the cell lumen near the base towards the top of the tree was observed (Figure 4).

The literature does not present data on the variation of anatomical characteristics in *S. parahyba* wood in the longitudinal direction. However, some studies show different patterns of variation of the fiber dimensions from the base to the top (Sette Jr. *et al.*, 2012; Gonçalez *et al.*, 2014) for other forest species, including Eucalyptus, as also observed in this study.

The vessel dimensions and frequencies differed significantly among the species, with higher mean values observed for *E. urophylla* (Table3): the frequency, tangential diameter and occupied area of vessels was higher in Eucalyptus than in Guapuruvu wood.

Table 3 - Frequency and vessel dimensions per species

Species	Frequency (vessels.mm^{-2})	Tangential diameter (µm)	Occupied area (%)
E. urophylla	25.4 * (7.5)	82.0 * (14.0)	22.7 * (6.9)
S. parahyba	7.5 (3.2)	27.5 (26.1)	10.1 (4.0)

Means followed by standard deviation. Student t-test: * p<0.05

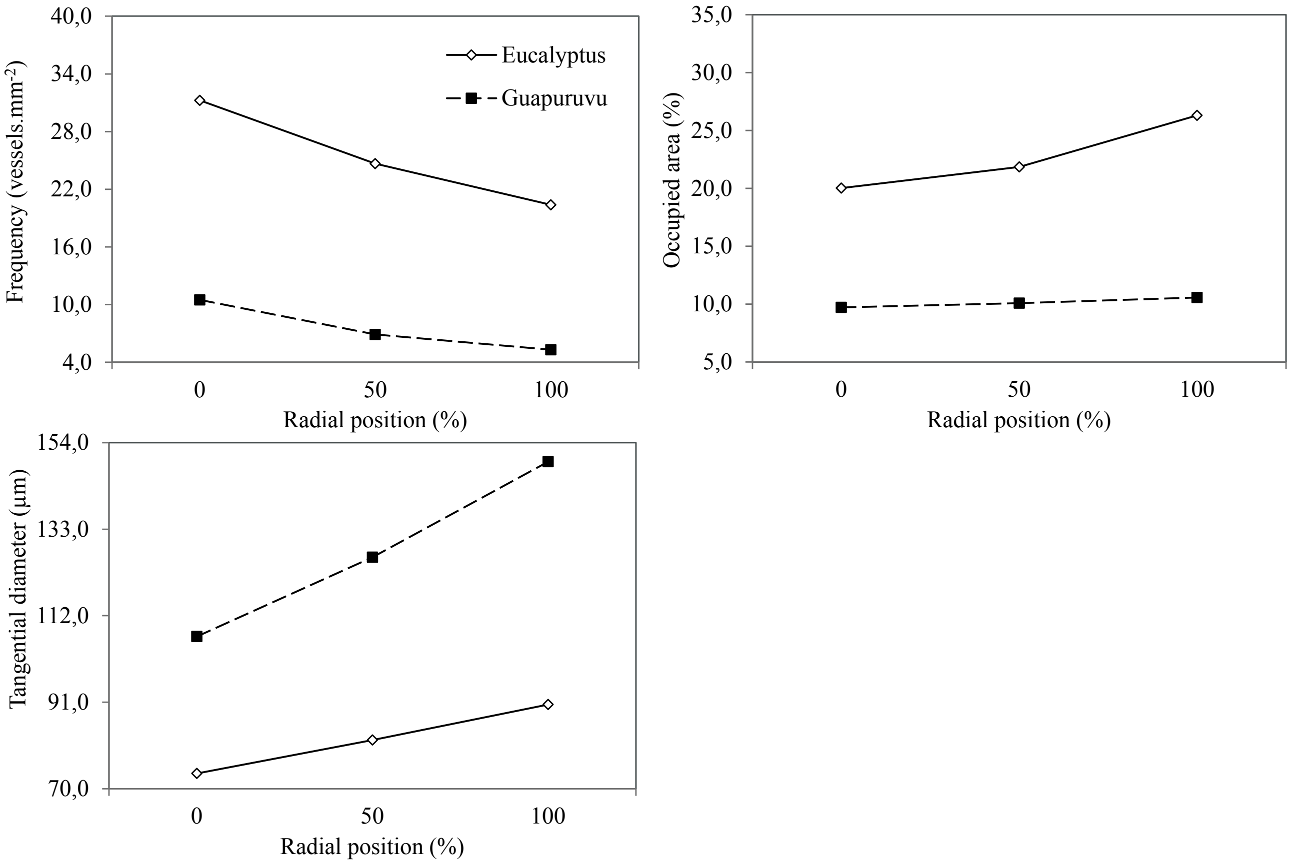

Figure 5 - Variation of fiber dimensions by species and longitudinal position.

The radial variation pattern of vessel frequency and dimensions (Figure 5) were similar to that of previous studies carried out with several species: increased vessel diameter and reduced frequency in pith-bark direction (Rocha *et al*., 2004; Sette Jr. *et al*.,2012). In the physiological aspect, changes in diameter, frequency and arrangement of vessels are interpreted by the need of the plants to increase their capacity of transporting water and minerals as their growth is increased and consequently their size increases. Under the technological aspect these changes reflect the physical-mechanical properties of wood, on drying and on the penetration of liquor in the chips during the delignification process.

The wood at the base of the trunk presented vessels with lower frequency, tangential diameter and area occupied than in other parts of the trunk, with a tendency to increase the values toward the top of the tree for both species studied (Figure 6). This result observed for vessels along with that observed for fiber dimensions (Figure 4) affects the wood basic density values: smaller sizes of vessels promote increased in wood density, as previously discussed.

The higher frequency and area occupied by the vessels at the top of the tree may be related to the increase in the physiologically active wood (sapwood; sapflow from roots to leaves) along the trunk in the base-top direction.

The evaluation of *Schizolobium parahyba* and *Eucalyptus urophylla* wood at more advanced ages is recommended to determine the variation of its anatomical and physical characteristics, as well as the mechanical properties and chemical characteristics (not contemplated in this study) to characterize the phase of its stabilization (formation of mature wood), which are important for its adequate technological use.

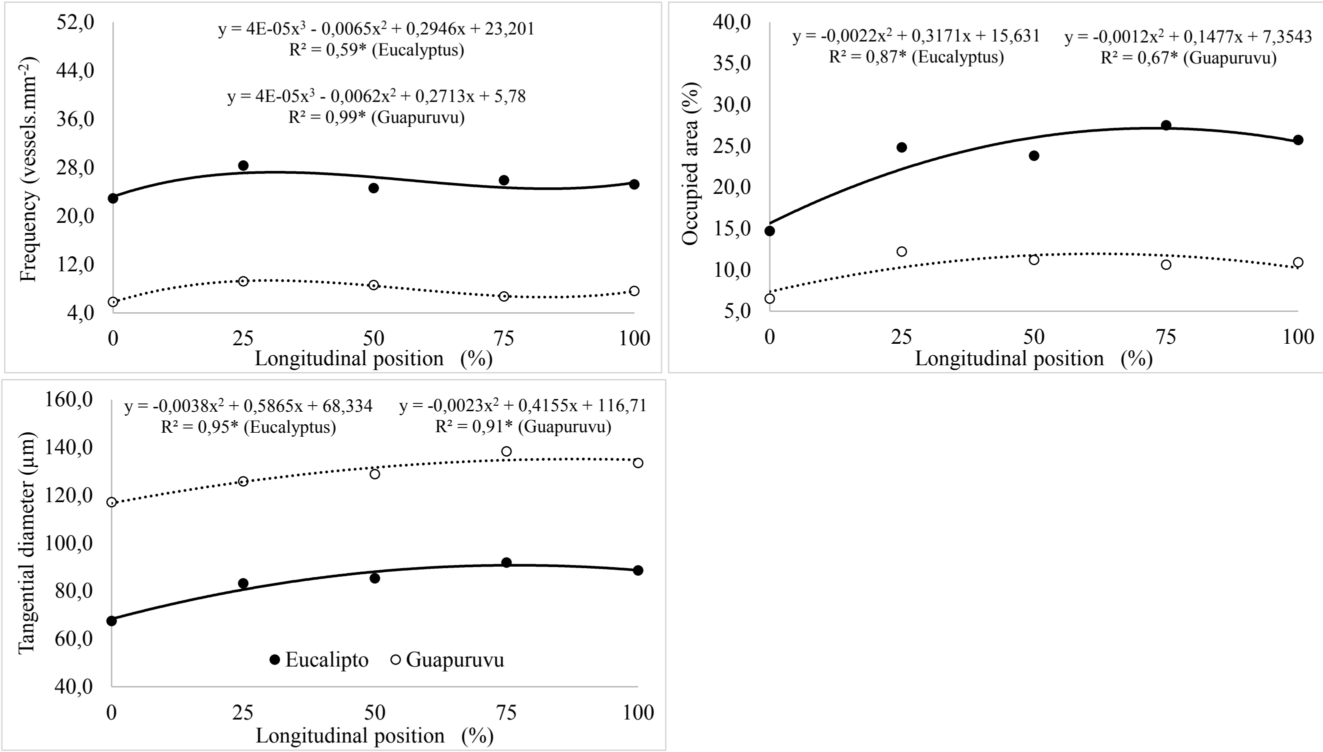

Figure 6 - Variation of vessel frequency and dimensions per species and longitudinal position.

CONCLUSIONS

The comparative analysis of the wood characteristics showed: (i) lower basic density, vessel dimensions and frequency; and (ii) larger width and lumen diameter of the fibers in the *Schizolobium parahyba* than the *Eucalyptus urophylla*. The average wood basic density *Schizolobium parahyba* was 0.27 $g.cm^{-3}$ and 0.40 $g.cm^{-3}$ for *Eucalyptus urophylla*, both at 3 years-old.

The longitudinal and radial variation patterns of the wood basic density and the anatomical characteristics of 3-year old *Schizolobium parahyba* and *Eucalyptus urophylla* trees planted in Brasilian Savanna soil showed that the cambium is still forming the juvenile wood.

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